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SOLAR POWER GENERATING SYSTEMS AS SOURCES OF NON-POLLUTING ENERGY (POWER GENERATION IN SPACE AND POWER GENERATION ON THE GROUND)

Tatsuo Tani and Takashi Horigome

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16. Abstract Various systems of solar power generation in space and on the ground which have been made public thus far are considered. In connection with the proposed American system for building solar power stations in space, the composition of the solar power stations and the microwave power transmission system, the efficiency of the microwave power transmission system, the method of delivering the power stations into orbit in space, and other related matters are discussed. Two systems for solar thermal power stations on the ground are outlined. The first is the system proposed by a group at the University of Arizona, and the second is one using an MHD generator. Research and development ought to be commenced immediately concerning solar thermal power generating systems on the ground.

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SOLAR POWER GENERATING SYSTEMS AS SOURCES OF NON-POLLUTING ENERGY

(POWER GENERATION IN SPACE AND POWER GENERATION ON THE GROUND)

Tatsuo Tani, Takashi Horigome[1]

1. Introduction /31*

Solar radiation energy is permanent energy of about 1.4 kW/m^2 in the atmosphere and about 1.0 kW/m^2 on the earth's surface; it can be considered to be a non-polluting energy source which will not damage living beings. Recently there has been a move towards utilizing positively this clean solar radiation energy in a way which will be helpful to the welfare of humanity [1, 2]. The system for this is the concept of solar power stations which would convert, by some method, solar radiation energy into convenient electrical energy. Various systems have been made public along this line. One of them, based on the space development techniques which have made rapid progress in recent years, is the plan to build solar power stations on orbits in space. Another one is a plan to build on the ground solar power stations which would condense solar radiation energy and convert this energy into electrical energy. In the background of these plans is the pronounced increase in the demand for electric power in countries all over the world in recent years. Were this demand to be met by the current techniques of generating electrical power, large amounts of fossil fuels, which cannot be regenerated,

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* Numbers in the margin indicate pagination in the foreign text.

[1] Member, Agency of Industrial Science and Technology, Electrotechnical Laboratory, Energy Department, Energy Transmission Research Section (T.T.), and Member, Agency of Industrial Science and Technology, Electrotechnical Laboratory, Energy Department, director of Energy Transmission Research Section (T.H.).

would be consumed, and their depletion would result. At the same time, the globe would be contaminated by the by-products such as sulfurous acid gas, radioactive wastes, and warm waste water, and there would be fear of leaving causes of worry for future generations.

This report explains and considers various systems of power generation utilizing solar radiation energy on the basis of the materials which have been reported thus far.

2. Solar Power Stations in Space and Microwave Power Transmission Systems

A plan concerning a solar power generating system in space which was recently announced in the United States and concerning which research has been commenced is not only vast in its concept; at the same time, much interest is attracted to it because its idea is to secure clean energy sources which will not exert any genetic effects on future generations of humanity. In space, by selecting the orbit suitably, it is possible to minimize greatly the screening time of the solar radiation energy.

Let us suppose that a solar power station has been constructed on a space orbit at an altitude of 35,600 km. Whereas the mean sunlight time ratio of the solar radiation energy on the earth's surface is about 18%, on this orbit the screening time of the solar radiation energy would be only 1.2 hours per day during the 25 days before and after the vernal and autumnal equinoxes. Even this time can be eliminated by combining two points at distances 10,000 km away from each other on the orbit, and it would be possible for power to be generated continously.

The target transmission capacity of the solar power sa stations which were made public at this time in the United States is 10 million kW per system. This is a large-scale system which would be capable of meeting 10% of the current demand for electricity in the United States (10^8 kW) [3].

On the other hand, there are also plans to build solar power stations in the atmosphere [4, 5]. These plans would involve building spacecraft in the vicinity of 20 km above ground, where there is comparatively little influence of the seasons and the weather. The composition of this system would basically be the same as that of the space power stations described above. The mean sunlight time of the solar radiation energy would be less in this system than in space orbit, but the launching system would be easier. The composition of these systems is one consisting of the various subsystems /32 shown in Fig. 1. In the following let us describe in outline the various subsystems of solar power stations.

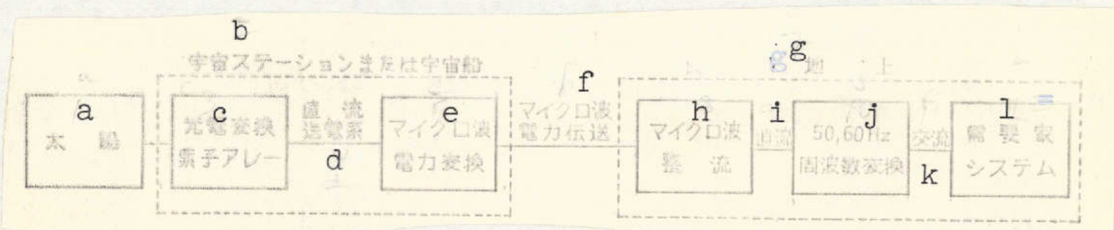

Fig. 1. Composition of a solar power generating system

Key:

a. Sun
b. Space station or spacecraft
c. Photoelectric conversion element array
d. D.C. transmission system
e. Microwave power conversion
f. Microwave power transmission
g. Ground
h. Microwave rectification
i. D.C.
j. 50, 60 Hz frequency conversion
k. A.C.
l. Customer system

2.1. Outline of Solar Power Station and Microwave Power Transmission System

(1) Photoelectric conversion device. This device uses numerous photoelectric conversion elements in series-parallel connections. Various types of photoelectric conversion elements have been developed, but at the present time they have a conversion efficiency of about 10%, and it is believed that this may possibly reach about 20% in the future. In order to obtain an output with a transmission capacity of 10 million kW by means of an array with many photoelectric conversion elements connected, at a conversion efficiency of 10.5% [6], it would be necessary to have a photoelectric conversion light-receiving area with a surface area of about 90 km^2. As the tasks of future technical development, one may mention improvements of the conversion efficiency and countermeasures against radioactive disturbances connected with the service life of the conversion elements in space.

(2) D.C. transmission system. This subsystem is a D.C. cable for transmitting the D.C. output of the photoelectric conversion device to the microwave power conversion device. It is presumed that this cable would be superconductive cable with ratings of 20 kV and 500 kA. The required length would be approximately 316 km. After cooling to an extremely low temperature, the required cooling power would be only about 1 kW, and it is believed that there would be few problems concerning cooling technology.

(3) Microwave power generation equipment. The use of amplitrons and magnetrons is considered as the microwave power oscillating equipment [7]. Amplitrons are manufactured with an oscillation frequency of 3 GHz and a continuous output of 100 kW, and their efficiency has reached 76%. Although magnetrons are inferior to amplitrons in their output, there are some with an efficiency of 86%. Since the demand for oscillating tubes of this type has been limited in the past to

to the communications field, there has been very little demand for large-capacity units. However, if there should be an increased demand for these devices for power transmission purposes, it is regarded as possible to improve their output by about two digits, and the efficiency would also presumably increase to more than 90%.

On the other hand, semiconductor oscillating elements have a small output of several watts at the present time. However, it is believed that they can be converted to a large capacity by adopting integrated circuits. Because they are easy to handle, it is quite conceivable that they will be used in the future.

If one were to use oscillating tubes to transmit power of 10 million kW, one might seriously assume that the equipment would consist of 5,000 amplitrons of 2,000 kW. In this case, an especially problematic point would be the cooling system for the cathodes and anodes. If operating at a conversion efficiency of 90%, the amount of heat generated would reach 10^6 kW. This heat would be radiated out into space from radiators located in the vicinity of the antennas. However, it is thought that positive use ought to be made of this if if could be extracted at a relatively high temperature.

(4) Transmission antennas. Antennas with a round or square aperture surface would be used as the transmission antennas. The transmission efficiency of the microwave beams is a function of the aperture area of the transmitting and receiving antennas, the transmission distance, and the wavelength. If the transmitting power is 10^7 kW, the aperture area of the transmission antennas would be 460 x 460 m^2 and 520 x 520 m^2 in cases when the wavelength of the microwave beams was 10 cm and the transmission efficiency was 80% and 90%, respectively [8].

(5) Receiving antennas. When microwave beam power of 10^7 kW is received, the maximum power density of the beams on the

receiving surface would be 100 mW/cm^2 if the transmission efficiency was 90%. Since this value would reach the danger level for birds, the aperture area of the receiving antennas ought to be calculated for 25 mW/cm^2, which is regarded as ecologically safe. In this case, the area would be 10.2 x 10.2 km for a transmission efficiency of 90%.

Rectinas, which, unlike ordinary radar antennas, combine both the functions of receiving and rectification, would be used as the receiving antennas [9]. These antennas are combinations of a half-wavelength dipole antenna and high-frequency semiconductor rectifying elements. The capacity of one element unit of this type is less than one watt at the present time (rectifying efficiency of microwave power with a wavelength of about 10 cm: 80-90%), and the overall /33 efficiency of the rectina is 50-55%. As the receiving efficiency is further improved in the future, it is expected that the comprehensive efficiency will be raised to 85-90% (oscillating frequency 1-3 GHz).

2.2. Efficiency of Microwave Power Transmission System

The results of indoor power transmission experiments conducted at NASA (the target value of the required output is approximately 27% when an output of 20-40 W is acquired). If we consider the possibility of future improvements and technological developments in the various subsystems, it is indicated that the comprehensive efficiency of the whole system may reach as high as 77%. The actual values under the current circumstances and the values anticipated in the future are shown in Table 1.

TABLE 1. CURRENT EFFICIENCY AND VALUES ANTICIPATED IN THE FUTURE

Items / Efficiency	Current efficiency (%)	Efficiency which can be expected with present technology (%)	Efficiency which can be anticipated in the future (%)
Microwave power generator	76.6	85.0	90.0
Transmission antennas and transmission efficiency	66.0	86.0	95.0
Receiving antennas and rectifying efficiency	52.0	70.0	90.0
Comprehensive efficiency	27.0	51.0	77.0

2.3. Method of Delivering Power Station to Space Orbit

Considering future technological developments, it is supposed that the total weight of this space station for power generation and transmission will be 20,000 - 50,000 t if the transmission capacity is 10 million kW [3]. The following delivery system is considered for these devices. That is, they would first be launched by rocket to a low orbit above the earth, where they would be assembled. After assembly, they would be carried by towing rocket, while generating electricity, to the stationary satellite orbit. Several months would be required for this. A Saturn V type rocket can launch a load of 120 tons at one time to allow orbit. It if were used, rockets would have to be fired some 200-400 times.

2.4. Plans for Developmental Research and Evaluation of Power Generating Costs

The plans for this research have a target date for completion after about 20 years, in the year 2,000 A.D. A power station for demonstration purposes would be built in the latter half of the 1980's, and in the 21st century electric power generated by space stations would be supplied to the customers.

The construction costs are evaluated at 160,000/kW. In this system, 60% of all the costs are taken up by the solar radiation energy collectors, and it is unavoidable that the cost per kW would be higher than the costs with current systems of power generation [3]. However, once the stations are built, the generation costs will not necessarily become any higher because no fuel at all is needed for power generation. More than anything else, the significance of this research must be sought in the fact that the energy is non-polluting energy.

3. Solar Thermal Power Stations on the Ground

The solar radiation energy which is received in immense amounts (173,000 x 16^6 MW) by the earth's surface is in actual fact the greatest energy source, and the technology for utilizing it is an extremely fascinating topic for development. The concept of solar thermal power stations is one of the systems which is being planned for converting solar radiation energy into electrical energy on the ground. Here let us described in outline two development research projects which are now being planned.

3.1. Outline of a Solar Thermal Power Generating System (1)

A research group at the Optics Center of the University of Arizona in the United States has recently proposed a concept for a solar thermal power station in which solar radiation energy would be converted into electric power [10, 11]. The American and Mexican governments are evincing great interest in this research. They note especially taht this system is provided with equipment, not only for power generation, but also for converting sea water from the Pacific Ocean into fresh water. Fig. 2 is an outline diagram of this system.

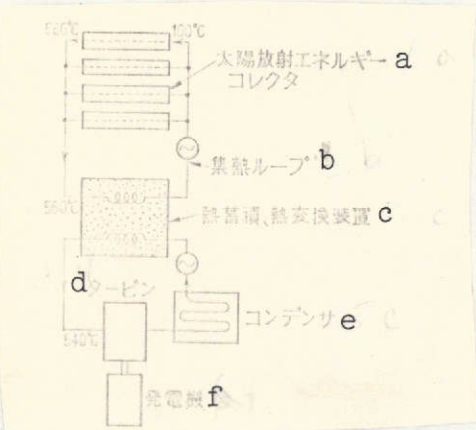

Fig. 2. Outline diagram of solar thermal power generating system

Key:

a. Solar radiation energy collector
b. Thermal collecting loop
c. Heat storage, heat conversion equipment
d. Turbine
e. Condenser
f. Generator

(1) Supply subsystem. This system consists of a special thin film and a liquid metal (Na, NaK, etc.) circulating system. This system collects the solar heat and supplies it to the storage subsystem [12].

(2) Storage subsystem. In this system, a medium which has a fusing point equal to the temperature at which a steam turbine can operate (1,000°F) is housed in a large container. Since the container is provided with suitable heat shielding, the heat can be stored up for a long period of time at a constant temperature. As a result, power can be generated continuously on the ground, even during the inevitable periods of rainy weather.

(3) Conversion subsystem. This system consists of a steam loop, a turbine generator, a heat exchanger, and pumps. Basically, it is the same as the system used in thermal and nuclear power stations.

Although this system has great initial construction costs, /34 once it has been constructed there are few maintenance costs and other necessary expenses. Thus, it is believed that the initial capital investment can be recovered economically. If this power station has a service life of 40 years, it will be able to generate power at a cost of only 2.0 yen per kW/h or less. Furthermore, if we suppose that the amount of solar radiation energy incident per unit of area is 0.8 kW, the comprehensive efficiency of this system is estimated at 31%, as shown in Table 2 [11].

TABLE 2. EFFICIENCY OF SOLAR THERMAL POWER STATION

Solar radiation energy	0.8 kW/m^2
Absorption x loss	0.75
Energy input	0.6 kW/m^2
Carnot's efficiency	0.55
Turbine efficiency	0.75
Effective energy	0.25 kW/m^2
Comprehensive efficiency	0.31

3.2. Outline of a Solar Thermal Power Generating System (2)

In this system, the solar radiation energy reaching the earth's surface is reflected by a reflection mirror, collected at the top of a tower 1,500 feet above the ground, introduced into a solar furnace and boiler, captured as heat of 2,000°C, and converted into electrical energy by an MHD generator [13]. Part of the electrical energy generated by the MHD generator is supplied to the customers by means of DC-AC converters. Another part of the output is used to manufacture hydrogen and oxygen, which are stored in ultra-low temperature containers and when necessary are converted into electrical or mechanical energy via fuel batteries and internal combustion engines. The comprehensive efficiency of this system is estimated at 20%, and if we suppose that the construction costs for building a steam turbine, the costs per one kWh would be approximately 1.8 yen.

4. Conclusion

We have described various solar power generating systems in outline. In this country many persons seem to consider space power stations as if they were something out of a fantastic story. However, in view of the recent citizens' movements opposing the construction of thermal and nuclear power stations as well as the restrictions on the use of electric power in some areas, we think that the time has come when we ought to make serious studies of non-polluting space power generating plans as a national project in the way of making technology assessments and in planning research and development.

On the other hand, with respect to solar thermal power generating systems on the ground, development and research ought to be commenced immediately from the standpoint of conserving non-polluting energy resources. For utilization on the industrial scale, large-scale condensing devices and thermal energy storage devices will be necessary. If if were possible to develop equipment capable of absorbing and converting solar radiation energy with a good efficiency, it might also be possible to make effective use of unused space on the ocean or in highly congested cities, and one might well expect that this would bring about immense changes in social life. It is most advisable to utilize solar radiation energy as a non-polluting energy source to take care of the energy demand of highly developed contemporary society before the fossil fuels become depleted, and we hope that there will be fruitful results of fundamental research in the near future.

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